

## CLAIMS

1. A method of decryption of an encrypted image having a non-encrypted image intensity pattern  $I(x',y')$  and

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Encoded into a mask having a plurality of mask resolution elements  $(x_m, y_m)$  with an encoded phase value  $\phi(x_m, y_m)$  and an encoded amplitude value  $a(x_m, y_m)$ , and

Encrypted by addition of an encrypting phase value  $\phi_c(x_m, y_m)$  to the encoded phase values

10  $\phi(x_m, y_m)$  and by multiplication of an encrypting amplitude value  $a_c(x_m, y_m)$  with the encoded amplitude value  $a(x_m, y_m)$ ,

Each mask resolution element  $(x_m, y_m)$  modulating the phase and the amplitude of electromagnetic radiation incident upon it with the complex value

15  $a(x_m, y_m)a_c(x_m, y_m)e^{i\phi(x_m, y_m)+i\phi_c(x_m, y_m)}$ , and

The method comprising the steps of

Radiating electromagnetic radiation towards the mask,

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Inserting into the path of the electromagnetic radiation a complex spatial electromagnetic radiation modulator comprising modulator resolution elements  $(x_d, y_d)$ , each modulator resolution element  $(x_d, y_d)$  modulating the phase and the amplitude of electromagnetic radiation incident upon it with a predetermined complex value  $a_d(x_d, y_d)e^{i\phi_d(x_d, y_d)}$ , the

25 decrypting phase value  $\phi_d(x_d, y_d)$  and the decrypting amplitude value  $a_d(x_d, y_d)$ , respectively, of a modulator resolution element  $(x_d, y_d)$  being substantially equal to  $-\phi_c(x_m, y_m)$  and  $a_c^{-1}(x_m, y_m)$ , respectively, of a corresponding mask resolution element  $(x_m, y_m)$ , and

Imaging the mask and the electromagnetic radiation modulator onto the image having the

30 image intensity pattern  $I(x',y')$ .

2. A method according to claim 1, wherein the step of imaging comprises imaging with a common path interferometer.

3. A method according to claim 1 or 2, wherein the step of imaging comprises phase contrast imaging.

4. A method according to claim 2 or 3, further comprising the steps of

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Fourier or Fresnel transforming electromagnetic radiation modulated by the mask and the complex spatial electromagnetic radiation modulator,

### Filtering the Fourier or Fresnel transformed electromagnetic radiation by

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**In a region of spatial frequencies comprising DC in the Fourier or Fresnel plane,**

Phase shifting with a predetermined phase shift value  $\theta$  the modulated electromagnetic radiation in relation to the remaining part of the electromagnetic radiation, and

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Multiplying the amplitude of the modulated electromagnetic radiation with a constant B, and

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In a region of remaining spatial frequencies in the Fourier or Fresnel plane, multiplying the amplitude of the modulated electromagnetic radiation with a constant A,

Forming the intensity pattern by Fourier or Fresnel transforming, respectively, the phase  
25 shifted Fourier or Fresnel transformed modulated electromagnetic radiation, whereby each  
resolution element  $(x_m, y_m)$  of the mask is imaged on a corresponding resolution element  
 $(x', y')$  of the image,

The filtering parameters  $A$ ,  $B$ ,  $\theta$  substantially fulfilling the equation

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$$I(x',y') = A^2 |a(x',y') e^{i\phi(x',y')} + \bar{\alpha} (BA^{-1} e^{i\theta} - 1)|^2$$

$\bar{\alpha}$  being the average of the complex phasors  $a(x,y)e^{i\phi(x,y)}$ .

5. A method according to claim 4, wherein the filtering parameters A and B substantially fulfil that  $A=1$  and  $B=1$ , and wherein the absorption of the mask is substantially uniform.

6. A method according to claim 5, wherein the phase shift value  $\theta$  substantially fulfils the  
5 equation

$$|\overline{\alpha}| = \frac{1}{2|\sin \frac{\theta}{2}|}$$

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7. A method according to claim 6, wherein the phase shift  $\theta$  is substantially equal to  $\pi$ .

8. A method according to any of claims 3-7, further comprising the steps of

15 Moving the DC-part of the electromagnetic radiation to a second part of the Fourier or  
Fresnel plane, and

Phase shifting the Fourier or Fresnel transformed modulated electromagnetic radiation at the second part of the Fourier or Fresnel plane by  $\theta$  in relation to the remaining part of the

20 electromagnetic radiation.

9. A method according to claim 8, wherein the step of moving the DC-part of the electromagnetic radiation comprises utilisation of an optical component, such as a grating, a prism, etc, with an appropriate carrier frequency.

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10. A method according to any of claims 3-9, further comprising the step of phase shifting at selected spatial frequencies constituting a region that is shaped to match the spatial frequency content of the phasors  $e^{i\phi(x,y)}$ .

30 11. A method according to any of claims 3-10, wherein the step of filtering comprises utilisation of a spatial light modulator.

12. A method according to any of claims 3-11, further comprising the step of encoding the optical function of an output lens into the filter.

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099
1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	

13. A method according to any of claims 3-12, wherein the step of radiating electromagnetic radiation comprises radiation of electromagnetic radiation of different wavelengths corresponding to three different colours, such as red, green and blue, for  
5 generation of intensity patterns of arbitrary colours.

14. A method of encryption of an image having an intensity pattern  $I(x',y')$  to be decrypted according to any of claims 1-13, comprising the steps of

10 Pixellating the intensity pattern  $I(x',y')$  in accordance with the disposition of resolution elements  $(x_m, y_m)$  of a mask,

Encoding the mask with an encoded phase value  $\phi(x_m, y_m)$  and an encoded amplitude value  $a(x_m, y_m)$ , and

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Encrypting by addition of an encrypting phase value  $\phi_c(x_m, y_m)$  to the encoded phase values  $\phi(x_m, y_m)$  and by multiplication of an encrypting amplitude value  $a_c(x_m, y_m)$  with the encoded amplitude value  $a(x_m, y_m)$ ,

20 Each mask resolution element  $(x_m, y_m)$  modulating the phase and the amplitude of electromagnetic radiation incident upon it with the complex value

$$a(x_m, y_m) a_c(x_m, y_m) e^{i\phi(x_m, y_m) + i\phi_c(x_m, y_m)}.$$

15. A method according to claim 14, further comprising the step of calculating the complex  
25 phasor values  $a(x, y) e^{i\phi(x, y)}$  of the encoder in accordance with

$$I(x', y') = A^2 |a(x', y') e^{i\phi(x', y')} + \bar{\alpha} (BA^{-1} e^{i\theta} - 1)|^2$$

For selected phase shift values  $\theta$ ,  $\bar{\alpha}$  being the average of the complex phasors

30  $a(x, y) e^{i\phi(x, y)}$ ,

Selecting, for each resolution element, one of two phasor values which represent a particular grey level.

16. A method according to claim 15, wherein the filtering parameters A and B substantially fulfil that  $A=1$  and  $B=1$ , and wherein the absorption of the mask is substantially uniform.

17. A method according to claim 16, wherein the step of calculating the phasor values  
5 comprises

Setting the reconstructed intensity of at least one resolution element  $(x_0', y_0')$  of the intensity pattern to zero, and

10 Calculating the phasor values  $e^{i\phi(x,y)}$  of the mask in accordance with

$$|\bar{\alpha}| = \frac{1}{2|\sin \frac{\theta}{2}|}$$

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$$I(x', y') = 2 \left[ 1 \mp \sin(\phi_{\bar{\alpha}} - \phi(x', y') + \frac{\theta}{2}) \right]$$

For selected phase shift values  $\phi$ ,  $\phi_{\bar{\alpha}}$  being the phase of  $\bar{\alpha}$ .

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18. A method according to claim 17, further comprising the step of selecting the phase shift  $\theta = \pi$ , selecting  $|\bar{\alpha}| = 1/2$ , and calculating the phasor values  $e^{i\phi(x,y)}$  of the encoder in accordance with

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$$I(x', y') = 2(1 - \cos(\phi(x', y')))$$

$$\int \int_{\text{encoder}} \sin(\phi(x, y)) dx dy = 0.$$

19. A method according to any of claims 14-18, further comprising the step of encoding the function of an optical component, such as a grating, a prism, etc, with an appropriate carrier frequency, into the mask.

5 20. A method according to any of claims 14-19, further comprising the step of adjusting the modulus of the Fourier transform of the complex phasors  $a(x,y)e^{i\phi(x,y)}$  at specific spatial frequencies in order to control the range of intensity levels of the reconstructed intensity pattern.

10 21. A method according to claim 20, wherein the step of adjusting the modulus of the Fourier transform of the complex phasors  $a(x,y)e^{i\phi(x,y)}$  at specific spatial frequencies comprises at least one of the following measures:

15 a) Adjusting the individual complex phasors  $a(x,y)e^{i\phi(x,y)}$  of the resolution elements of the mask maintaining prescribed relative intensity levels between intensities of resolution elements of the intensity pattern,

b) Adjusting the individual complex phasors  $a(x,y)e^{i\phi(x,y)}$  of the resolution elements of the mask by histogram techniques,

20 c) Spatially scaling the complex phasor  $a(x,y)e^{i\phi(x,y)}$  pattern of the mask, and

d) Utilising half tone coding techniques.

25 22. A method according to any of claims 14-21, wherein each complex phasor  $a(x,y)e^{i\phi(x,y)}$  of the mask is selected from a set of two determined phasors with complementary complex phasor values  $a(x,y)e^{i\phi_1(x,y)}$  and  $a(x,y)e^{i\phi_2(x,y)}$  in such a way that a specific spatial frequency distribution of the intensity of the electromagnetic radiation in the Fourier or Fresnel plane is attained.

30 23. A method according to claim 22, wherein the phase  $\phi(x,y)$  of complex phasors  $a(x,y)e^{i\phi(x,y)}$  of adjacent resolution elements alternates between the two possible complementary complex phasor values  $a(x,y)e^{i\phi_1(x,y)}$  and  $a(x,y)e^{i\phi_2(x,y)}$ .

24. A method according to claim 22 or 23, wherein the complex phasors  $a(x,y)e^{i\phi_1(x,y)}$  and  $a(x,y)e^{i\phi_2(x,y)}$  are complex conjugated.

25. A method according to any of claims 14-24, further comprising the step of encoding the  
5 optical function of a Fourier-transforming lens into the complex phasors  $a(x,y)e^{i\phi(x,y)}$  of the encoder.

26. A method according to any of claims 14-25, wherein each of the encrypting phase  
10 values  $\phi_c(x_m, y_m)$  is substantially equal to a value selected from a set consisting of two phase values.

27. A method according to claims 26, wherein each of the encrypting phase values  $\phi_c(x_m, y_m)$  is substantially equal to a value selected from the set consisting of 0 and  $\pi$ .

15 28. A decryption system for decrypting an encrypted image having a non-encrypted image intensity pattern  $I(x', y')$  that has been

Encoded into a mask having a plurality of mask resolution elements  $(x_m, y_m)$  with an encoded phase value  $\phi(x_m, y_m)$  and an encoded amplitude value  $a(x_m, y_m)$ , and

20 Encrypted by addition of an encrypting phase value  $\phi_c(x_m, y_m)$  to the encoded phase values  $\phi(x_m, y_m)$  and by multiplication of an encrypting amplitude value  $a_c(x_m, y_m)$  with the encoded amplitude value  $a(x_m, y_m)$ ,

25 Each mask resolution element  $(x_m, y_m)$  modulating the phase and the amplitude of electromagnetic radiation incident upon it with the complex value  $a(x_m, y_m)a_c(x_m, y_m)e^{i\phi(x_m, y_m)+i\phi_c(x_m, y_m)}$ ,

The system comprising

30 A source of electromagnetic radiation for emission of electromagnetic radiation for illumination of the mask,

A complex spatial electromagnetic radiation modulator that is positioned in the path of the  
35 electromagnetic radiation and comprising modulator resolution elements  $(x_d, y_d)$ , each

modulator resolution element  $(x_d, y_d)$  modulating the phase and the amplitude of electromagnetic radiation incident upon it with a predetermined complex value  $a_d(x_d, y_d)e^{i\phi_d(x_d, y_d)}$ , the decrypting phase value  $\phi_d(x_d, y_d)$  and the decrypting amplitude value  $a_d(x_d, y_d)$ , respectively, of a modulator resolution element  $(x_d, y_d)$  being substantially equal to  $-\phi_c(x_m, y_m)$  and  $a_c^{-1}(x_m, y_m)$ , respectively, of a corresponding mask resolution element  $(x_m, y_m)$ , and

An imaging system for imaging the mask and the electromagnetic radiation modulator onto the image having the image intensity pattern  $I(x', y')$ .

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29. A system according to claim 28, wherein the imaging system comprises a common path interferometer.

30. A system according to claim 28 or 29, wherein the imaging system comprises a phase contrast imaging system.

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31. A system according to claim 29 or 30, further comprising

Means for Fourier or Fresnel transforming the electromagnetic radiation modulated by the mask and the complex spatial electromagnetic radiation modulator and being positioned on a propagation axis of the modulated radiation,

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A spatial filter for filtering the Fourier or Fresnel transformed electromagnetic radiation by

In a region of spatial frequencies comprising DC in the Fourier or Fresnel plane,

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Phase shifting with a predetermined phase shift value  $\theta$  the modulated electromagnetic radiation in relation to the remaining part of the electromagnetic radiation, and

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Multiplying the amplitude of the modulated electromagnetic radiation with a constant B, and



In a region of remaining spatial frequencies in the Fourier or Fresnel plane, multiplying the amplitude of the modulated electromagnetic radiation with a constant A,

- 5 Means for forming the intensity pattern by Fourier or Fresnel transforming, respectively, the phase shifted Fourier or Fresnel transformed modulated electromagnetic radiation, whereby each resolution element  $(x_m, y_m)$  of the mask is imaged on a corresponding resolution element  $(x', y')$  of the image,

- 10 The filtering parameters A, B,  $\theta$  substantially fulfilling the equation

$$I(x', y') = A^2 |a(x', y') e^{i\phi(x', y')} + \overline{\alpha} (BA^{-1} e^{i\theta} - 1)|^2$$

For selected phase shift values  $\theta$ ,  $\overline{\alpha}$  being the average of the complex phasors

- 15  $a(x, y) e^{i\phi(x, y)}$ .

32. A system according to claim 31, wherein the filtering parameters A and B substantially fulfil that  $A=1$  and  $B=1$ , and for each  $(x, y)$  of the encoder:  $a(x, y)=1$ .

- 20 33. A system according to claim 32, wherein the phase shift value  $\theta$  substantially fulfils the equation

$$|\overline{\alpha}| = \frac{1}{2|\sin \frac{\theta}{2}|}$$

- 25 34. A system according to claim 33, wherein the phase shift  $\theta$  is substantially equal to  $\pi$ .

35. A system according to any of claims 30-33, further comprising

Means for moving the region of spatial frequencies comprising DC to a second part of the

- 30 Fourier or Fresnel plane, and wherein

The spatial filter is adapted to phase shift the transformed modulated electromagnetic radiation at the second part of the Fourier or Fresnel plane by  $\theta$  in relation to the remaining part of the electromagnetic radiation.

5 36. A system according to claim 35, wherein the means for moving the region of spatial frequencies comprising DC to a second part of the Fourier or Fresnel plane comprises an optical component, such as a grating, a prism, etc, with an appropriate carrier frequency.

37. A system according to any of claims 31-36, wherein the spatial filter comprises a spatial  
10 light modulator.

38. A system according to any of claims 31-37, wherein the spatial filter is adapted to perform the optical function of an output lens by appropriate encoding of the spatial filter.

15 39. A system according to any of claims 28-38, wherein the source of electromagnetic radiation is adapted to radiate electromagnetic radiation of different wavelengths corresponding to three different colours, such as red, green and blue, for generation of intensity patterns of arbitrary colours.

20 40. A system according to any of claims 31-39, further comprising a first and a second Fourier transforming lens, the mask being positioned in the front focal plane of the first lens, the spatial filter being positioned at the back focal plane of the first lens, and the second lens being positioned so that its front focal plane is positioned at the position of the back focal plane of the first lens.

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41. A system according to any of claims 31-40, further comprising one Fourier transforming lens, the spatial filter being positioned at the back focal plane of the lens.

42. A system according to any of claims 31-41, further comprising one imaging lens, the  
30 spatial filter being positioned in the back focal plane of the lens.

43. A system according to any of claims 31-42, further comprising a polarising beam splitter and a quarter wave plate and/or a phase filter reflecting electromagnetic radiation incident upon it.

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44. A system according to any of claims 31-43, wherein the spatial filter changes the phase of the radiation in the region of spatial frequencies comprising DC and leaves the phase of the remaining part of the radiation unchanged.

5 45. A system according to any of claims 31-43, wherein the spatial filter do not change the phase of the radiation in the region of spatial frequencies comprising DC and changes the phase of the remaining part of the radiation.

46. A system according to any of claims 31-43, wherein the spatial filter blocks the  
10 radiation at the region of spatial frequencies comprising DC and leaves the remaining part of the radiation unchanged.

47. A system according to any of claims 31-46, wherein the source of electromagnetic radiation is a Laser.

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48. A system according to any of claims 28-47, wherein each of the encrypting phase values  $\phi_c(x_m, y_m)$  is substantially equal to a value selected from a set consisting of two phase values.

20 49. A method according to claims 48, wherein each of the encrypting phase values  $\phi_c(x_m, y_m)$  is substantially equal to a value selected from the set consisting of 0 and  $\pi$ .